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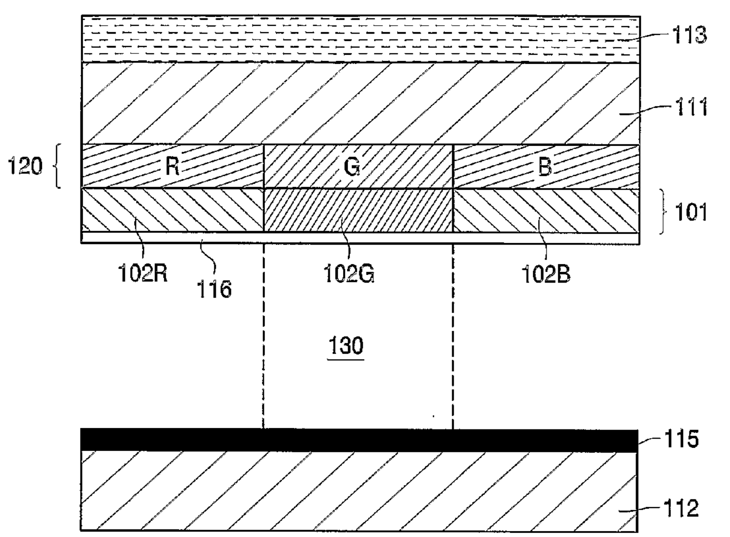
(54) **Title:** LIQUID CRYSTAL DISPLAY DEVICE




(57) **Abstract:** A color LCD device has a liquid crystalline cell arranged between a front substrate (111) and a rear substrate (112). The device further comprises a color filter (120) having regions (R, G, B) associated with the primary colors of the LCD. For improving the contrast ratio and brightness of the LCD, the device also includes a retarder layer (101). According to the invention, the retarder layer (101) is patterned and has portions (102R, 102G, 102B) of different retardation, which portions are associated with the primary colors of the LCD. Preferably, the retarder layer is a quarter wave retarder. A preferred manufacturing method is based on manipulating the order parameter of a liquid crystalline mixture, whereby at different process temperatures the birefringence value for a portion of the layer is fixed by polymerizing the mixture within said portion.

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# Liquid Crystal Display device

The invention relates to a Liquid Crystal Display (LCD) device.

Liquid crystal displays (LCDs) are increasingly the display of choice for a wide range of applications, such as television sets, computer monitors, handheld and automotive devices.

The operation of LCDs is based on light modulation in a liquid crystalline (LC) cell including an active layer of a liquid crystalline material, which cell is sandwiched between a front substrate and a rear substrate. By applying an electric field over the active layer, the light passing through the layer of LC material is modulated.

LCDs are generally operable in one or both of two modes, namely a transmissive mode and a reflective mode. In a transmissive LCD, light originating from a backlight is modulated by the LC layer. An inherent drawback of a transmissive LCD is the dependency of the optical characteristics on the viewing angle, i.e. the angle at which a viewer observes the display. Especially at oblique viewing angles, the displayed image has a reduced contrast ratio and suffers from grey scale inversion.

In a reflective LCD, ambient light is modulated by the LC layer and reflected back towards the viewer. However, the reflective LCD suffers from relatively limited brightness and contrast.

The optical characteristics of LCD devices can be improved by applying one or more layers showing optical birefringence. In a reflective LCD often so-called retarder layers (or foils) are used. The use of retarder layers is nowadays common in for example reflective or transflective LCD panels for use in handheld devices and mobile phones. An example of a commonly employed retarder layer in such devices is a quarter wave retarder, forming circularly polarized light from linearly polarized light or vice versa.

Conventionally, the retarder is formed externally from the LC cell. The retardation is then determined by the retarder thickness d, thus the thickness of the compensation layer is chosen in accordance with the desired retardation. The optically active layer has to be sandwiched in between protection layers, or applied onto a carrier sheet. The

optical element thus formed is glued to the substrate of the LC cell. As a result, the LCD device becomes undesirably thick and its optical performance is limited due to parallax.

While the retarder does improve the contrast ratio and brightness of the LCD device, this improvement is still relatively limited.

It is an object of the invention to further improve the contrast ratio and brightness of an LCD device.

This object has been achieved by an LCD device according to the independent Claim 1. Further advantageous embodiments are specified in dependent Claims 2 and 3.

It is a further object of the invention to provide a manufacturing process for an optical element that allows the brightness and contrast of an LCD device to be further improved.

This object has been achieved by the process according to the independent Claim 4. Further advantageous embodiments are specified in dependent Claims 5 and 6.

Thus, the retarder layer of the LCD device is a patterned retarder layer that has a number of portions each having a different retardation. Each portion of the patterned retarder layer is associated with one of the primary colors of the LCD. Generally these are red, green and blue.

The operation of the retarder is generally dependent on the ratio between the retardation R and the wavelength $\lambda$ of the incident light. For good performance, the retardation should be matched with that wavelength. For example, if the retardation is 550 nm / 4 = 138 nm, the retarder foil is a quarter wave ($\lambda/4$) retarder matched to the wavelength of green light (550 nm). In this case, the retarder foil gives good contrast and brightness for green light, but its performance for red and blue light is worse. Because of this, the contrast ratio and brightness of the LCD device are relatively limited.

According to the invention, the retardation of a portion of the patterned retarder layer is therefore conditional on a wavelength of the light of the associated primary color. If each portion of the patterned retarder is matched with one of the primary colors, the brightness and contrast can be as good as possible for all primary colors and thus for the entire LCD device.

The retardation R is given by the formula:

$$R = d\,\Delta n \qquad (1),$$

wherein d is the thickness of the retarder layer and $\Delta n$ the optical birefringence of the retarder material. The optical birefringence $\Delta n$ is commonly defined as the difference between the material's indices of refraction in the ordinary and extraordinary ray directions.

It is convenient if the retarder layer has essentially the same thickness d for each portion. In a LCD device, if the thickness were different for different portions, this would have to be compensated for mechanically, requiring extra planarization layers to be added to the device. Therefore, preferably, the retardation R of the portion of the patterned retarder layer is essentially determined by its optical birefringence value $\Delta n$.

More preferably, each portion of the patterned retarder acts as a quarter wave ($\lambda/4$) retarder for the light of the primary color associated with that portion. As a result, the patterned retarder layer is a quarter wave retarder for each primary color and the contrast ratio and brightness are as high as possible.

The birefringence of an aligned nematic or smectic mixture is dependent on the anisotropy of polarization of the mixture components, and on the order parameter of the mixture. The order parameter S is defined for a liquid crystalline material as

$$S = \frac{1}{2}\left\langle 3\cos^2\Theta - 1\right\rangle \qquad (2),$$

where $\Theta$ represents the angle between the director of a molecule and the normal vector. For an isotropic material S=0 , and an order parameter S=1 indicates perfect alignment, i.e. substantially each molecule has its axis aligned with the normal vector.

The order parameter itself is dependent on the temperature. Thus, by changing the temperature, the birefringence and the retardation of the mixture can be altered.

The process according to the invention relies on this insight. After the aligning step, the temperature is set to a first process temperature, at which the mixture has an optical birefringence corresponding to a first value. First portions of the mixture are polymerized and/or cross-linked whereby for those first portions a polymer network is formed. Consequently, the birefringence is fixed for the first portions of the layer. The polymer network retains the first birefringence value.

Subsequently, the temperature is set to a second process temperature, at which the non-polymerized part of the mixture obtains an optical birefringence corresponding to a second value. This part is then also polymerized and/or cross-linked whereby a polymer network is formed.

In order to make a retarder layer in a LCD device, preferably a layer of the mixture is provided on a surface within the LCD device. More preferably, the retarder layer is arranged inside the liquid crystalline cell as this allows for optical performance that is as good as possible. The retarder is then for example provided on a surface of the front substrate, which surface faces the active layer. In a color LCD device, it can be applied directly over the color filter on the side thereof facing the active layer.

The manufacturing process according to the invention is then carried out on the mixture layer. The thickness of the layer is known, and a patterned retarder layer is obtained of which the retardation of the different portions matches a desired retardation with high precision. Thus, a retarder layer may be manufactured which improves the brightness and contrast ratio of the liquid crystalline cell as well as possible.

In general, a patterned layer is formed having first portions and second portions with different birefringence values and thus different retardation. For example, the first portions have a retardation of 138 nm so that the first portions act as a quarter wave ($\lambda$ /4) retarder for green light. The second portions may be isotropic and have zero retardation; in this case the second process temperature was above the clearing temperature of the mixture.

During the manufacturing process, the polymerization step preferably includes photo-polymerization through a mask. By using a patterned mask, portions of the layer can be defined with relative ease. For example, at the first process temperature, white areas of the mask pass UV radiation so that first portions of the layer are polymerized and/or cross-linked, and black areas of the mask absorb the UV radiation so that second portions of the layer remain in their liquid crystalline state.

Thus, the inventors have achieved to manufacture a patterned retarder layer with a region size of 100 micrometers, but patterning with even higher resolution should be feasible.

This region size is comparable to the size of a picture element of the liquid crystalline cell. As a result, a retarder layer having such patterning is particularly suitable for use in an LCD device. The regions of the patterned retarder layer can be associated with the color subpixels of the LCD device. Because the patterned retarder layer can be applied inside the liquid crystalline cell, this does not lead to parallax effects in the LCD. Patterned retarder layers allow for particularly good optical performance of the LCD device.

Preferably, the process further includes a polymerization step at a third process temperature. This allows for first, second and third portions to be defined within the mixture

layer. In this case, each portion can match one of the primary colors red, green and blue, as in the LCD device according to the invention.

The process may include further polymerization steps at different temperatures, so that a patterned retarder layer with more than three portions having different birefringence may be obtained. Such a layer could be useful for instance in a multi-primary LCD device, i.e. a LCD device having more than three primary colors.

An alternative manufacturing process relies on a step of converting a photo-isomerizable compound in the mixture for changing the birefringence. In this process the mixture is irradiated through a grey scale mask, preferably under an oxygen containing atmosphere. This process is set out in more detail in applicant's copending unpublished patent application PHNL030326.

The invention will now be elucidated further with reference to the enclosed drawings, which are drawn schematically and not to scale. In the drawings:

Fig. 1 shows an embodiment of an LCD device according to the invention;

Fig. 2 shows an embodiment of the manufacturing process according to the invention;

A first embodiment of a liquid crystalline cell for a LCD is shown in Fig. 1. The LCD device further comprises driver electronics not shown in the drawing. It is noted that the drawing only shows one color pixel, i.e. three primary color sub-pixels, whereas an actual Liquid Crystal Display has a large number of pixels, for example 320x240 color pixels and thus 960x240 sub-pixels.

The LC cell illustrated here is a reflective cell based on the Twisted Nematic (TN) effect. An electric field may be applied perpendicularly to the liquid crystalline (LC) layer 130 by applying a voltage difference across the reflective electrode 115 and the transmissive electrode 116, usually an indium tin oxide (ITO) electrode.

When zero voltage or a minimum driving voltage is applied, unpolarized ambient light incident onto the LC cell passes through a linear polarizer 113 on substrate 111, the color filter 120 and a $\lambda/4$ retarder layer 101 before entering the LC layer 130. The color filter 120 selectively passes linearly polarized light of the different primary colors through

the color filter regions associated with the primary colors (indicated by R, G and B in the drawing).

Thus, linearly polarized light that is separated into the primary colors is obtained. This linearly polarized light is then circularly polarized by the retarder layer 101, before entering the LC layer 130. On the other side of the LC layer 130, the reflective electrode 115 including a so-called internal diffusive reflector (IDR) is arranged, which reflects and diffuses the part of the incident light arriving at the reflector back towards a viewer.

An initial twist angle of the liquid crystal molecules is for example 90 degrees. Without any voltage, the twisted LC layer 130 causes the circularly polarized light exiting from the $\lambda/4$ retarder 101 to be linearly polarized when arriving at the reflector 115. This linearly polarized light is then reflected back, and regains its original circular polarization when arriving at the $\lambda/4$ retarder 101. The $\lambda/4$ retarder 101 converts the circularly polarized light back to linearly polarized light having its original linear polarization so that it is able to pass back through the polarizer 113 and exit the cell towards a viewer.

However, when a maximum driving voltage is applied between the electrodes 115 and 116, the liquid crystalline cell is changed to its dark state.

The liquid crystal molecules align with the applied electric field, and the initial twist angle of the molecules disappears. Thus, the circularly polarized light exiting from the $\lambda/4$ retarder 101 passes through the LC layer 130 and thereby effectively experiences a low birefringence. Consequently the light is still circularly polarized when it arrives at the reflector 115. Upon reflection, the circular polarization is reversed causing the light to have an opposite circular polarization. The light still has this opposite circular polarization when arriving at the $\lambda/4$ retarder 101 and therefore the $\lambda/4$ retarder 101 now converts the light to a linear polarization state having a polarization direction perpendicular to the original linear polarization direction. Thus, this linearly polarized light has a polarization direction perpendicular to the polarization axis of the polarizer 113 and is absorbed by the polarizer 113. No light exits from the liquid crystalline cell so that a viewer observes a dark state.

In this embodiment, the retarder layer 101 is a patterned retarder layer that has three regions 102R, 102G, 102B. In each region, the retardation of the quarter wave retarder is matched with the wavelength of one of the primary colors red, green and blue. In particular, the retardation is matched with the wavelength of the primary color associated with the adjacent color filter region. In the following, this configuration will be referenced to as a "color-patterned retarder layer".

When a retarder with a constant retardation is used, the retarder is usually optimized for green light, for example the retardation is (550/4)=138 nm. A liquid crystalline cell of the electrically controlled birefringence (ECB) type, incorporating such a retarder has for example a contrast ratio of 17 for green. However, the contrast ratio for red is only 7, and the contrast ratio for blue is as small as 6. The ECB cell includes an active layer of a non-twisted nematic liquid crystalline material with planar alignment.

In the first embodiment of the LCD device according to the invention, the retardation of the retarder layer 101 is adapted for each primary color, i.e. the retardation is 138 nm for the green region 102G, (650/4)=163 nm for the red region 102R, and (450/4)=112 nm for the blue region 102B.

The contrast ratio of the ECB cell is now relatively high for all primary colors. For example, the contrast ratio for green is still 17, but for red it increases to 11 and for blue to 9. As a result, an increase in contrast ratio of 50% is obtained for the red and blue sub-pixels.

Such color-patterned retarder may readily be manufactured by means of the process according to the invention, wherein a patterned mask is used that comprises white (fully transmissive for the applied radiation) and black (fully reflective for the applied radiation) areas.

A suitable embodiment of the process is shown in Fig. 2. Firstly, an aligned liquid crystalline layer 201 is provided on substrate 211, as set out in the following Example.

EXAMPLE

A reactive liquid crystal mixture was made by dissolving

1 g 1,4-phenylene-bis-[4-(6-acryloyloxy)methyl-oxy)]benzoate (ex Merck),

0.25 g 1,4-phenylene-bis-[4-(6-acryloyloxy)hexyl-oxy)]benzoate (ex Merck),

0.25 g 4-(hexyloxy)-benzoyloxy-phenyl 4-4-(4-methyl-2,6,7-trioxa-bicyclo (2,2,2) oct-1-yl)-butyloxy) benzoate,

0.05 g Irgacure 651 (α,α-dimethoxydeoxybenzoin) (ex Ciba Geigy, Switzerland), and

0.05 g (2-n-ethylperfluoro-octanesulfonamido)-ethylacrylate (ex Acros),

into 7.5 g xylene at a temperature of 70 °C.

1,4-phenylene-bis-[4-(6-acryloyloxy)methyl-oxy)]benzoate, 1,4-phenylene-bis-[4-(6-acryloyloxy)hexyl-oxy)]benzoate, and 4-(hexyloxy)-benzoyloxy-phenyl 4-4-(4-methyl-2,6,7-trioxa-bicyclo (2,2,2) oct-1-yl)-butyloxy)benzoate are reactive LC monomers,

Irgacure 651 is a photoinitiator, and (2-n-ethylperfluoro-octanesulfonamido)-ethylacrylate is a surfactant to obtain planar alignment.

This mixture was spin-coated on top of an alignment layer being a rubbed polyimide substrate 211. The spin condition was 30 s at 735 rpm followed by 30 s at 3000 rpm. This leads to a retardance of 138 nm. The rubbed polyimide substrate 211 establishes a planar alignment in a monodomain of the LC monomers in the rubbing direction.

After providing the aligned layer 201, the temperature is set to a first process temperature T1. The white area of the mask 205 is arranged over a first portion 202R of the aligned mixture layer 201. The order of the mixture in the first portion 202R is fixed by a UV mask exposure for 2 min in a nitrogen atmosphere. Thereby, the mixture in the first portion 202R is crosslinked and its birefringent value is fixed (Fig. 2B). The layer thickness is well determined by the spincoating conditions. The first process temperature T1 is then chosen such that the retardation of the first portions 202R of the layer 201 becomes about 163 nm. The first portions 202R of the layer 201 then act as a quarter wave ($\lambda$ /4) retarder for red light (wavelength 650 nm).

The temperature is then raised to a second process temperature T2 at which second portions 202G of the layer 201 are polymerized (Fig. 2C). The white area of the mask 205 is shifted to overlap with these second portions 202G, and the same irradiation process is carried out for photo-polymerizing the mixture. The second process temperature T2 is chosen such that the retardation of the second portions of the layer is about 137 nm. The second portions 202G then act as a quarter wave ($\lambda$ /4) retarder for green light (wavelength 550 nm). It is noted that during this step, the birefringence of the first portions 202R remains the same so that the retardance of this part of the layer is not affected by the higher temperature.

Finally, the temperature is raised to a third process temperature T3 at which third portions 202B of the layer 201 are polymerized (Fig. 2D). The third process temperature T3 is chosen such that the retardation of the third portions 202B of the layer 201 is about 112 nm. The third portions 202B then act as a quarter wave ($\lambda$ /4) retarder for blue light (wavelength 450 nm). Again, the birefringence of the first and second portions 202R, 202G of the layer 201 is fixed and their retardance is not changed by the higher temperature.

Thus, a color-patterned retarder layer for an LCD device can easily be manufactured. In this example, portions of the layer were polymerized at three different process temperatures, corresponding to the three primary colors of a conventional color LCD device. However, a color-patterned retarder for a multi-primary LCD device, i.e. a LCD

device with more than three primary colors, is easily manufacturable by increasing the number of polymerization steps accordingly.

In general, using similar processes, a retarder layer with any desired patterning can be envisaged, where the birefringence of the different regions may vary within a relatively large range. In the case of a retarder layer, the layer thickness is essentially the same for the different regions. The different retardation of the different regions is predominantly determined by the different birefringence values.

An example of a quarter-wave retarder with a further improved contrast ratio is based on the wide-band quarter-wave retarder already known for several decades [S. Pancharatnam, Proc. Indian Ac. Sci. XLI, no.4, sec. A (1955)].

The wide-band quarter-wave retarder comprises a combination of a half-wave plate with its optical axis at 15° with respect to the polariser direction and a quarter-wave retarder with its optical axis at 75° with respect to the polariser direction. In this case the leakage in the dark state is already considerably reduced if compared to that of a simple quarter-wave retarder. An ECB cell incorporating such a wide-band retarder has for example a contrast ratio of 155 for green, whereas the contrast ratio for red may be only 60, and the contrast ratio for blue may be as small as 46.

Also in this example, the contrast ratio is improved by optimizing the retardation value for the half-wave retarder and the quarter-wave retarder for each color sub-pixel. By adapting the retardation for each primary color, the contrast ratio for green is still 155, but for red it increases to 107 and for blue to 88.

The drawings are schematic and not drawn to scale. While the invention has been described in connection with preferred embodiments, it should be understood that the invention should not be construed as being limited to the preferred embodiments. Rather, it includes all variations, which could be made thereto by a skilled person, within the scope of the appended claims.

In summary, a color LCD device is disclosed having a liquid crystalline cell arranged between a front substrate (111) and a rear substrate (112). The device further comprises a color filter (120) having regions (R,G,B) associated with the primary colors of the LCD. For improving the contrast ratio and brightness of the LCD, the device also includes a retarder layer (101). According to the invention, the retarder layer (101) is patterned and has portions (102R, 102G, 102B) of different retardation, which portions are associated with the primary colors of the LCD. Preferably, the retarder layer is a quarter wave retarder. A preferred manufacturing method is based on manipulating the order

parameter of a liquid crystalline mixture, whereby at different process temperatures the birefringence value for a portion of the layer is fixed by polymerizing the mixture within said portion.

CLAIMS:

1. A Liquid Crystal Display (LCD) device, comprising

a liquid crystalline cell for receiving and selectively passing incident light, said cell being sandwiched between a front substrate (111) and a rear substrate (112),

wherein said LCD device further comprises a patterned retarder layer (101) comprising portions (102R, 102G, 102B) each having a different optical birefringence,

and wherein the LCD device comprises a color filter (120) having regions (R, G, B) being arranged for forming light of a primary color corresponding to that region from the incident light, a retardation of a portion (102R, 102G, 102B) of the patterned retarder layer being conditional on a wavelength of light of an associated primary color.

2. The LCD device of Claim 1, wherein the retardation of the portion of the patterned retarder layer is essentially determined by a birefringence value.

3. The LCD device of Claim 1, wherein a portion of the patterned retarder layer acts as a quarter wave (λ/4) retarder for the light of the primary color associated with that portion.

4. A manufacturing process for a birefringent optical element comprising a number of portions each having a different optical birefringence, including the steps of:

- providing a mixture (201) with at least a liquid crystalline compound having a nematic or smectic phase, said compound including a polymerizable group;
- aligning the mixture (201);
- at a first process temperature, cross-linking and/or polymerizing first portions (202R) of the aligned mixture (201), thereby fixing an optical birefringence of said first portions (202R) and
- at a second process temperature, cross-linking and/or polymerizing second portions (202G) of the aligned mixture (201), thereby fixing an optical birefringence of said second portions (202G).

5. The process of Claim 4, wherein a polymerizing step includes photo-polymerization through a mask (205).

6. The process of Claim 4, further including the step of

- at a third process temperature, cross-linking and/or polymerizing third portions (202B) of the aligned mixture (201), thereby fixing an optical birefringence of said third portions (202B).

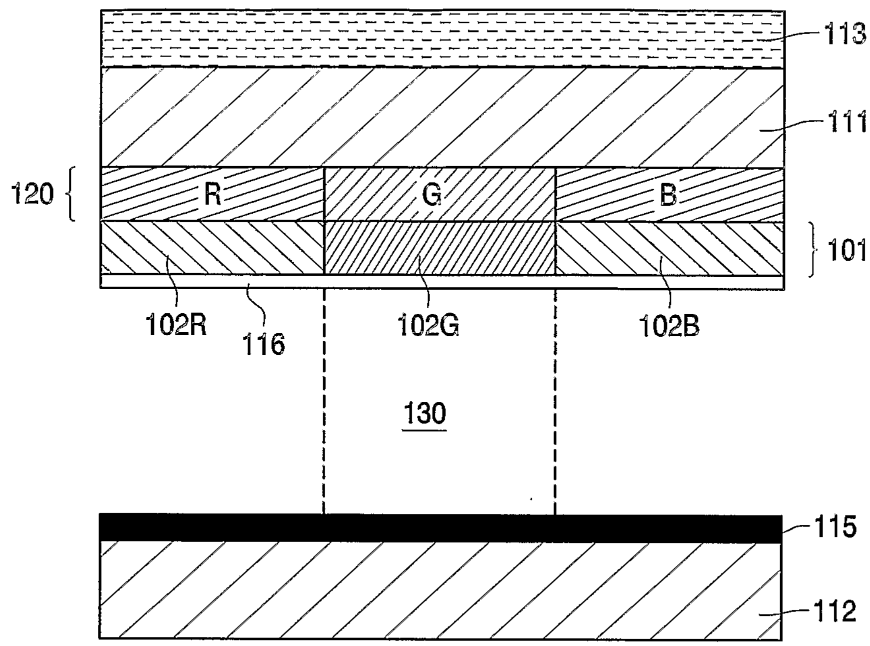


FIG. 1

FIG. 2A

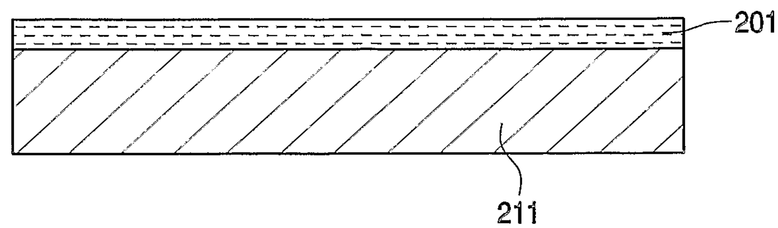


FIG. 2B

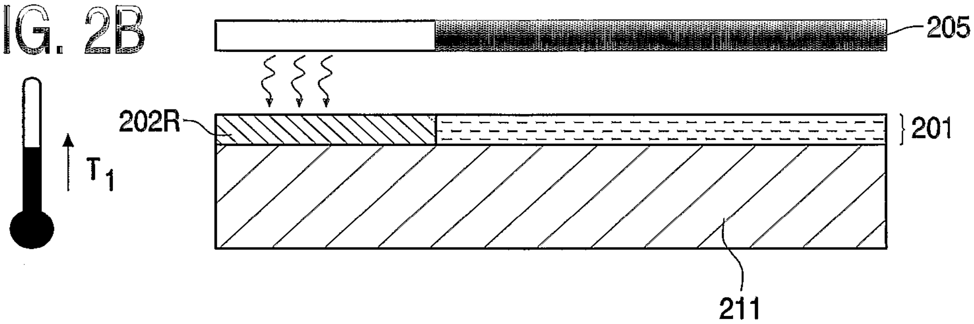


FIG. 2C

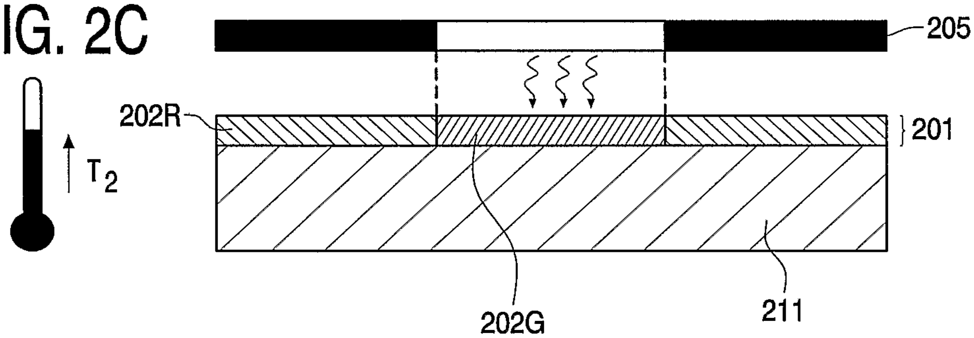


FIG. 2D